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# Earth Tech Inc.'s Enhanced In-Situ Bioremediation Process

## Innovative Technology Evaluation Report

National Risk Management Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

# Notice

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# Foreword

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL) is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threaten human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments and ground water; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by: developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

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Hugh W. McKinnon, Director
National Risk Management Research Laboratory

# Abstract

This report summarizes the findings of an evaluation of an enhanced in-situ bioremediation technology developed by the U.S. Department of Energy (DOE) at the Westinghouse Savannah River Plant site in Aiken, South Carolina and implemented by Earth Tech Inc. at the ITT Industries Night Vision (ITTNV) Division plant in Roanoke, Virginia. This evaluation was conducted between March 1998 and August 1999 under the U.S. Environmental Protection Agency Superfund Innovative Technology Evaluation (SITE) Program. The area focused on during the demonstration was immediately downgradient of a solvent release area. At this locality, several volatile organic compounds (VOCs) had been measured at concentrations above regulatory levels in both upper and lower fractured zones of the underlying shallow bedrock. Four specific VOC compounds were designated as "critical parameters" for evaluating the technology: chloroethane (CA), 1,1-dichloroethane (1,1-DCA), cis-1,2-dichloroethene (cis-1,2-DCE), and vinyl chloride (VC).

The primary objective of the demonstration was to evaluate Earth Tech's claim that there would be a minimum 75% reduction with a 0.1 level of significance (LOS) in the groundwater concentrations for each of the four critical analytes, following six months of treatment. The demonstration results indicated, that on an overall average, concentrations levels of all four critical VOCs were measured to be reduced from baseline to final events as follows: CA (35%); 1,1-DCA (80%); cis-1,2-DCE (97%); and VC (96%). The lower confidence limit (LCL) and upper confidence limit (UCL) were also calculated for percent contaminant reduction. The LCL can be thought of as the most conservative estimate of reduction. The UCL can be thought of as the best possible reduction the technology may have achieved. The 90% confidence intervals (LCL-UCL) for the four compounds were: CA (4 - 54%); 1,1-DCA (71 - 86%); cis-1,2-DCE (95 - 98%); and VC (92 - 98%). Therefore, cis-1,2-DCE and VC achieved the 75% reduction goal with a 0.1 LOS; 1,1-DCA was just under this goal at 71% LCL and CA reduction was barely significant at 4% LCL.

Acetone and isopropanol (IPA), the two non-chlorinated compounds analyzed for during the demonstration, were detected at significant levels in just one of the wells sampled. On an overall average, concentrations of acetone and IPA were measured to be reduced from baseline to final events in this upper zone well by 94% and 96%, respectively. The 90% confidence intervals (LCL-UCL) for acetone and IPA were 78-96% and 86-98%, respectively.

The lower fractured zone of the bedrock aquifer was the focus of the demonstration groundwater sampling. However, samples were also collected from an upper fractured zone at a reduced frequency. The data were useful for evaluating treatment of VOCs contained in fractures above the injection depth. The results indicated the technology had a greater impact in the upper fractured zone, where higher initial concentrations of the same VOCs were reduced by larger percentages.

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# Abbreviations and Acronyms

| | |
|---|---|
| ABT | Acoustic borehole televiewer |
| AODC | Acridine orange direct counts |
| AQCR | Air Quality Control Regions |
| AQMD | Air Quality Management District |
| ARARs | Applicable or Relevant and Appropriate Requirements |
| bls | Below land surface |
| CA | Chloroethane |
| CAA | Clean Air Act |
| CERCLA | Comprehensive Environmental Response, Compensation, and Liability Act |
| $CO_2$ | Carbon dioxide |
| $CH_4$ | Methane |
| cis-1,2-DCE | cis-1,2-Dichloroethene |
| CFR | Code of Federal Regulations |
| CSCT | Consortium for Site Characterization Technologies |
| cfu | Colony forming units |
| cfm | Cubic feet per minute |
| CWA | Clean Water Act |
| 1,1-DCA | 1,1-Dichloroethane |
| 1,1-DCE | 1,1-Dichloroethene |
| DNA | Deoxyribonucleic acid (RE: gene detection and approximation) |
| DNAPL | Dense non-aqueous phase liquid |
| DO | Dissolved oxygen |
| DOE | U.S. Department of Energy |
| EPA | U.S. Environmental Protection Agency |
| Earth Tech | Earth Tech, Inc. of Concord, MA |
| FS | Feasibility study |
| $ft^2$ | Square feet |
| $ft^3$ | Cubic feet |
| G&A | General and administrative |
| HSWA | Hazardous and Solid Waste Amendments |
| HP | Horsepower |
| ITER | Innovative Technology Evaluation Report |
| ITTNV | ITT Industries Night Vision |
| IW | Injection well |
| IM | Interim measure |
| IPA | Isopropanol, or Isopropyl alcohol |
| kW-hr | Kilowatt hours |
| LCSs | Laboratory control samples |

## Abbreviations and Acronyms (Cont'd)

| | |
|---|---|
| LCL | Lower confidence limit |
| LEL | Lower explosive limit |
| LNAPL | Light non-aqueous phase liquid |
| LOS | Level of significance |
| MCLs | Maximum contaminant levels |
| MCLGs | Maximum contaminant level goals |
| mg/l | Milligrams per liter |
| MW | Monitoring well |
| MPN | Most probable number (RE: total culturable methanotrophs) |
| NAAQS | National Ambient Air Quality Standards |
| NCP | National Oil and Hazardous Substances Pollution Contingency Plan |
| NPDES | National Pollutant Discharge Elimination System |
| NRMRL | National Risk Management Research Laboratory (EPA) |
| NSCEP | National Service Center for Environmental Publications |
| ND | Non-detectable, or not detected at or above the method detection limit |
| NPDWS | National primary drinking water standards |
| NTU | Normal turbidity unit |
| OSHA | Occupational Safety and Health Administration |
| ORD | Office of Research and Development (EPA) |
| OSWER | Office of Solid Waste and Emergency Response (EPA) |
| OSC | On-scene coordinator |
| ORP | Oxidation/reduction potential |
| $O_2$ | Oxygen |
| PLFA | Phospholipid fatty acids |
| ppbv | Parts per billion by volume |
| ppmv | Parts per million by volume |
| PPE | Personal protective equipment |
| PQL | Practical quantitation limit |
| PLC | Programmable logic controller |
| psi | Pounds per square inch |
| PVC | Polyvinyl chloride |
| POTW | Publicly owned treatment works |
| QA/QC | Quality assurance/Quality control |
| QAPP | Quality assurance project plan |
| RFI | RCRA Facility Investigation |
| RI/FS | Remedial Investigation / Feasibility Study |
| RPM | Remedial project manager |
| RCRA | Resource Conservation and Recovery Act |
| RSK | R.S. Kerr Environmental Research Laboratory |
| SARA | Superfund Amendments and Reauthorization Act |
| SAIC | Science Applications International Corporation |
| scfh | Standard cubic feet per hour |
| SDWA | Safe Drinking Water Act |
| SM | Standard method |
| SG | Soil gas |

## Abbreviations and Acronyms (Cont'd)

| | |
|---|---|
| SVE | Soil vapor extraction |
| SOP | Standard operating procedure |
| SW-846 | Test methods for evaluating solid waste, physical/chemical methods |
| SWDA | Solid Waste Disposal Act |
| SITE | Superfund Innovative Technology Evaluation |
| S.U. | Standard units |
| 3-D | Three dimensional |
| TR | Trace |
| 1,1,1-TCA | 1,1,1-Trichloroethane |
| TCE | Trichloroethene |
| TEP | Triethyl phosphate |
| TER | Technology Evaluation Report |
| TCH | Total culturable heterotrophs |
| TO-14 | Total organics - method 14 (gas analysis) |
| TOC | Total organic carbon |
| µg/l | Micrograms per liter |
| µS/cm | Micro siemens per centimeter |
| UCL | Upper confidence level |
| USEPA | United States Environmental Protection Agency |
| VC | Vinyl chloride |
| VADEQ | Virginia Department of Environmental Management |
| VOCs | Volatile organic compounds |

## Acknowledgments

This report was prepared under the direction of Mr. Vicente Gallardo, the EPA Technical Project Manager for this SITE demonstration at the National Risk Management Research Laboratory (NRMRL) in Cincinnati, Ohio. EPA review of this report was conducted by Mr. Gallardo, Dr. Ronald Lewis (retired), Dr. Tamara Marsh, and Dr. Ronald Herrmann. Ms. Deborah Goldblum of the EPA Region 3 is the project coordinator overseeing the RCRA Facility Investigation and Corrective Measures being performed at the ITT Night Vision site. Dr. Brian Looney of the Savannah River Technology Center provided helpful insight into the PHOSter™ technology capabilities.

The demonstration required the combined services of several individuals from Earth Tech Inc., ITTNV Industries, and Science Applications International Corporation (SAIC). Ms. Rosann Kryczkowski served as on-site project coordinator for ITTNV and Mr. Gregory Carter served as the on-site project coordinator for Earth Tech, Inc. Ms. Barbara Lemos served as the Earth Tech project manager. Dr. Scott Beckman of SAIC served as the SITE work assignment manager for the implementation of demonstration field activities and completion of all associated reports. The cooperation and efforts of these organizations and individuals are gratefully acknowledged.

This report was prepared by Joseph Tillman, Rita Stasik and Dan Patel of SAIC. Ms. Stasik also served as the SAIC Quality Assurance (QA) Coordinator for data review and validation. Andrew Matuson served as SAIC field manager. Joseph Evans (the SAIC QA Manager) internally reviewed the report. Field sampling and data acquisition was conducted by Mike Bolen, Andrew Matuson, Christina Paniccia, and Joseph Tillman of SAIC; and John Huisman of Matrix Environmental.

# Executive Summary

This report summarizes the findings of an evaluation of the Earth Tech Enhanced In-Situ Bioremediation treatment process. The process was evaluated for its effectiveness for treating groundwater contaminated with elevated levels of volatile organic compounds, including chlorinated compounds. The study was conducted at the ITT Industries Night Vision (ITTNV) Division plant in Roanoke, Virginia. This evaluation was conducted under the U.S. EPA Superfund Innovative Technology Evaluation (SITE) Program.

## Overview of Site Demonstration

The Enhanced In-Situ Bioremediation Process is a biostimulation technology developed by the U.S. Department of Energy (DOE) at the Westinghouse Savannah River Plant site in Aiken, South Carolina. DOE, who refers to their technology as PHOSter™, has licensed the process to Earth Tech, Inc. of Concord, MA (Earth Tech). Earth Tech is utilizing the process to deliver a gaseous phase mixture of air, nutrients, and methane to contaminated groundwater in fractured bedrock. These enhancements are delivered to groundwater via an injection well to stimulate and accelerate the growth of existing microbial populations, especially methanotrophs. This type of aerobic bacteria has the ability to metabolize methane and produce enzymes capable of degrading chlorinated solvents and their degradation products to non-hazardous constituents.

A pilot-scale technology demonstration of the enhanced in-situ bioremediation system was conducted from March 1998 to August 1999 at the ITTNV Division plant in Roanoke, Virginia. The ITTNV facility is an active manufacturing plant that produces night vision devices and related night vision products for both government and commercial customers. Groundwater contamination has been detected at several areas at the facility. The area focused on during the demonstration is immediately downgradient of a solvent release source area. At this locality, several volatile organic compounds (VOCs) have been measured at concentrations above regulatory levels in both an upper and lower fractured zone in the underlying shallow bedrock. Four specific VOC compounds were designated as "critical parameters" for evaluating the technology: chloroethane (CA); 1,1-dichloroethane (1,1-DCA); cis-1,2-dichloroethene (cis-1,2-DCE); and vinyl chloride (VC).

The pilot treatment system that Earth Tech installed within the area of contamination consisted of eleven monitoring points, including an injection well, four monitoring wells located within the anticipated radius of influence, two monitoring wells located outside of the anticipated radius of influence, and four soil vapor monitoring points. The four wells located in the anticipated radius of influence were designated as "critical wells", based on their location and the temporal and spatial variability for the four critical parameters measured within those wells. Collecting samples daily from these wells represented a conservative basis for ensuring sample independence based upon the groundwater gradient. During the demonstration, one of the monitoring wells was temporarily converted to a second injection well.

Over the duration of the demonstration combinations of air, nutrients, and methane were injected into the lower fractured zone approximately 43 feet below land surface. Although emphasis was placed on evaluating treatment effectiveness at the injection depth, groundwater in both the upper and lower fractured zones of the bedrock was sampled and analyzed by the SITE Program.

## Conclusions from this SITE Demonstration

A number of conclusions may be drawn from the evaluation of the Earth Tech Enhanced Bioremediation process, based on extensive analytical data supplemented by field measurements. These include the following:

- On an overall average, concentrations levels of all four critical VOCs were measured to be reduced from baseline to final events as follows: CA (35%); 1,1-DCA (80%); cis-1,2-DCE (97%); and VC (96%). The 90% lower and upper confidence limit intervals (LCL-UCL) for the four compounds were: CA (4-54%); 1,1-DCA (71-86%); cis-1,2-DCE (95-98%); and VC (92-98%). Therefore, cis-1,2-DCE and VC achieved the 75% reduction goal with a 0.1 LOS; 1,1-DCA was just under this goal at 71% LCL and CA reduction was barely significant at 4% LCL.
- The results of the microbial analyses were highly variable, but did suggest that the treatment system was able to stimulate the indigenous microorganisms to degrade the target contaminants. The phospholipid fatty acid (PLFA) data, which provides a biomass measurement for the entire microbial community, was the most consistent of all the microbial data collected. PLFA increased by an order of magnitude following the first intermediate sampling event and then remained fairly constant throughout the remainder of the demonstration.
- Comparison of upper and lower zone data suggests that treatment effectiveness may have been greater in the upper zone. In the immediate area of treatment, the summed total for the four critical VOCs in upper zone wells was reduced on average by 91% from baseline to final sampling events, as compared to 39% for lower zone wells. This is believed to be due to the upward airflow pathways from the injection point at 43 feet below land surface up to shallower depths.
- Microbial data seemed to lend support to the above conclusion. For example, total culturable heterotroph (TCH) and PLFA concentrations in the upper fractured zone attained significantly higher levels than in the lower fractured zone. There was also significant concentration drops in total culturable methanotrophs as measured by the most probable number technique (MPN), TCH, and PLFA in the lower fractured zone six days after the injection system was turned off. However, there was not a significant drop concentration drop for those three parameters in the upper fractured zone. TCH and MPN levels actually increased in the upper zone six days after the injection system was turned off. The methane, oxygen, and nutrients could have migrated upward from the injection point to the upper fractured zone, thus lowering microbial levels in the lower zone and enriching the levels in the upper zone. Therefore, a depletion of methanotrophs could have occurred in the lower fractured zone at the same time a population increase occurred in the upper fractured zone.
- Acetone and IPA, the two non-chlorinated compounds analyzed for during the demonstration, were detected at significant levels in just one of the wells sampled. On an overall average, concentrations of acetone and IPA were measured to be reduced from baseline to final events in this upper zone well by 94% and 96%, respectively. The 90% confidence intervals (LCL-UCL) for acetone and IPA were 76- 98% - and 86-98%, respectively.
- There is evidence to suggests that anomalously high baseline groundwater elevations may have diluted VOC baseline concentrations, thus biasing low observed VOC reductions. The highest concentrations of critical VOCs were measured during a December 1997 pre-demonstration sampling event, during a period of depressed water levels. However, just three months later during the demonstration baseline sampling event heavy precipitation had caused the raising of the groundwater to peak elevations. An inverse relationship between groundwater levels and contaminant concentrations prior to start of treatment suggests that the critical VOC concentrations were diluted by more than half (i.e., from ~ 11,600 µg/l to ~ 5,500 µg/l). Thus, the VOC reductions reported for the demonstration may be conservative.

- VOC soil gas data were variable and inconclusive with respect to determining VOC sparging into the upper vadose zone as a result of injecting gases into the lower saturated zone. Of the four soil vapor monitoring points sampled, two showed order of magnitude increases for averaged total critical VOCs from baseline to six months after baseline (only one of which showed a steady increase). A third monitoring point showed an order of magnitude decrease over the same time period; a fourth showed no appreciable change.

- The estimated cost to remediate an approximate 23,000 $ft^2$ area to a depth of 40 feet of VOC-contaminated groundwater over a two year period is \$370,000. This assumes that a 40- foot thick section of bedrock would be affected, thus an estimated 900,000 $ft^3$ of contaminated fractured bedrock is assumed treated. The cost would convert to \$16/$ft^2$ or \$0.40/$ft^3$ if the injection depth was 40 feet bls. If the injection campaign needs to be extended at the same site, the cost over a 3-, or 4-year period is estimated to increase to approximately \$440,000 (\$19/$ft^2$ or \$0.48/$ft^3$), and \$520,000 (\$23/$ft^2$ or \$0.57/$ft^3$), respectively.